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G2J
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(54) **Fibre optic coupling device**

(57) A light concentrator/expander device for collecting light for transmission into or from a fibre optic bundle (32) includes a solid transparent member (26) consisting of a parabolic section and a truncated conical section (20). An aplanatic lens (32') may be spaced across an air gap from the small diameter end (22) of the member (26). An ellipsoidal reflector (30) may be positioned with a filament lamp (28) at its first focus and with the small end (22) at its second focus.

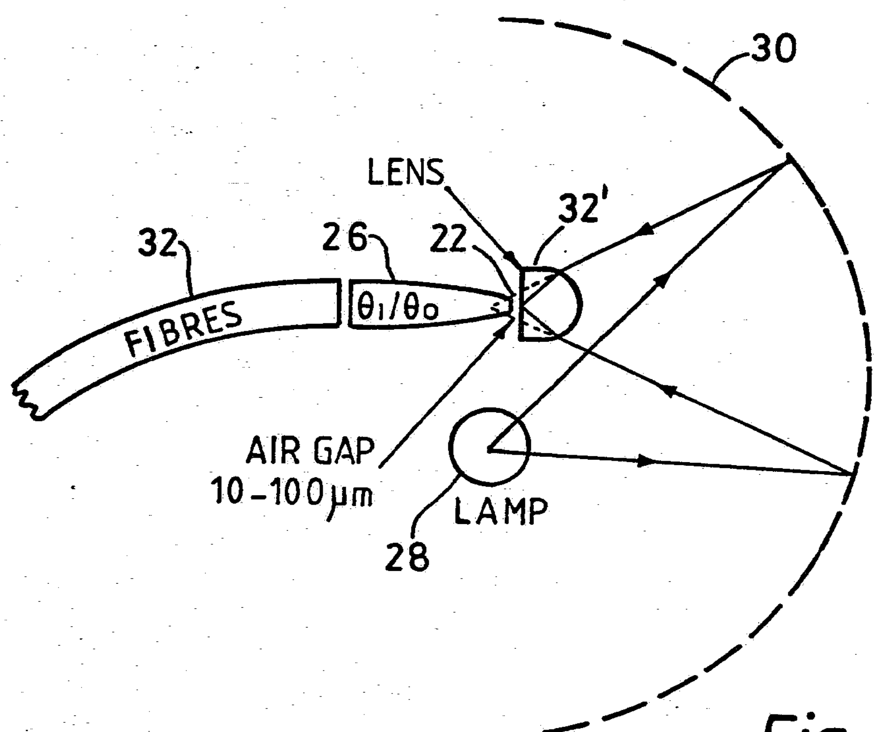

Fig.3

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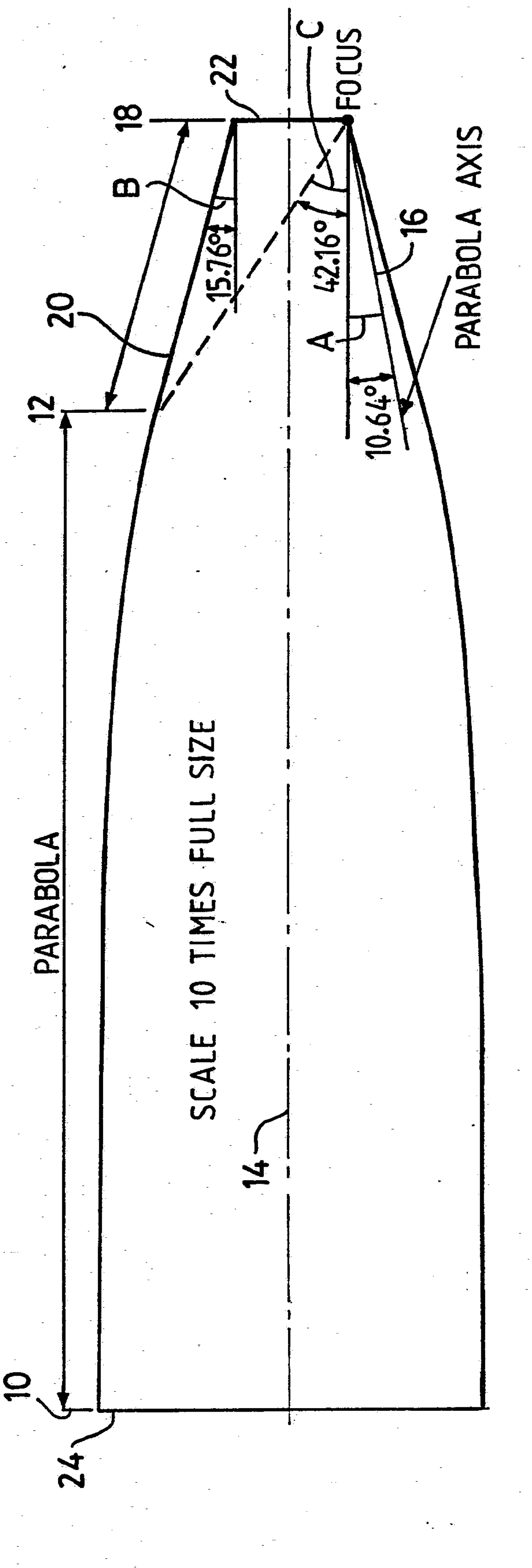
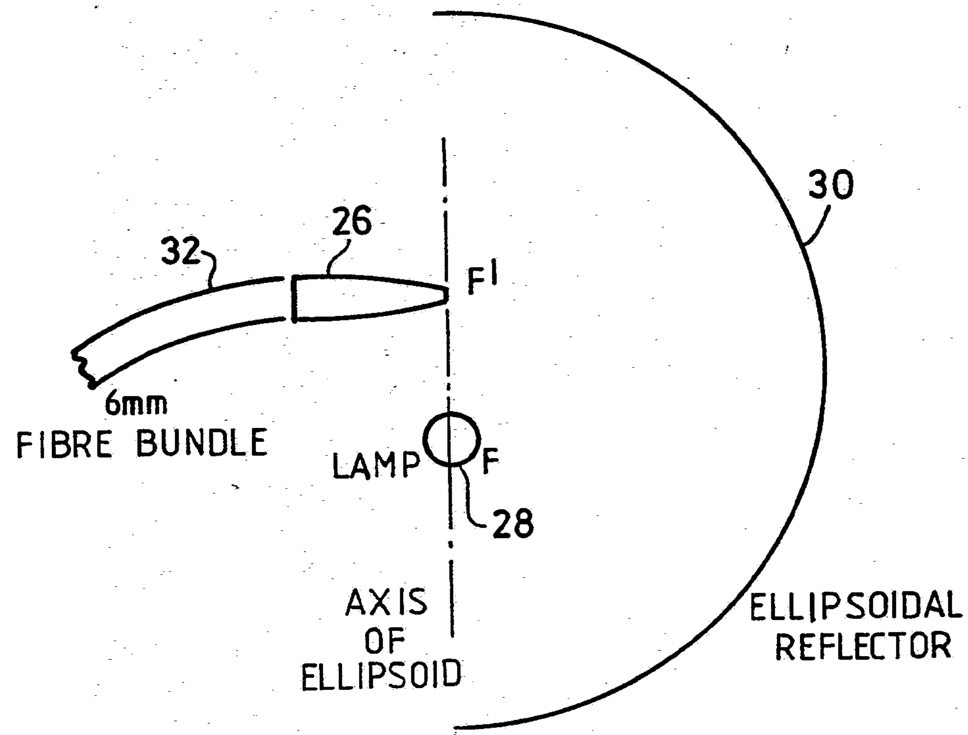
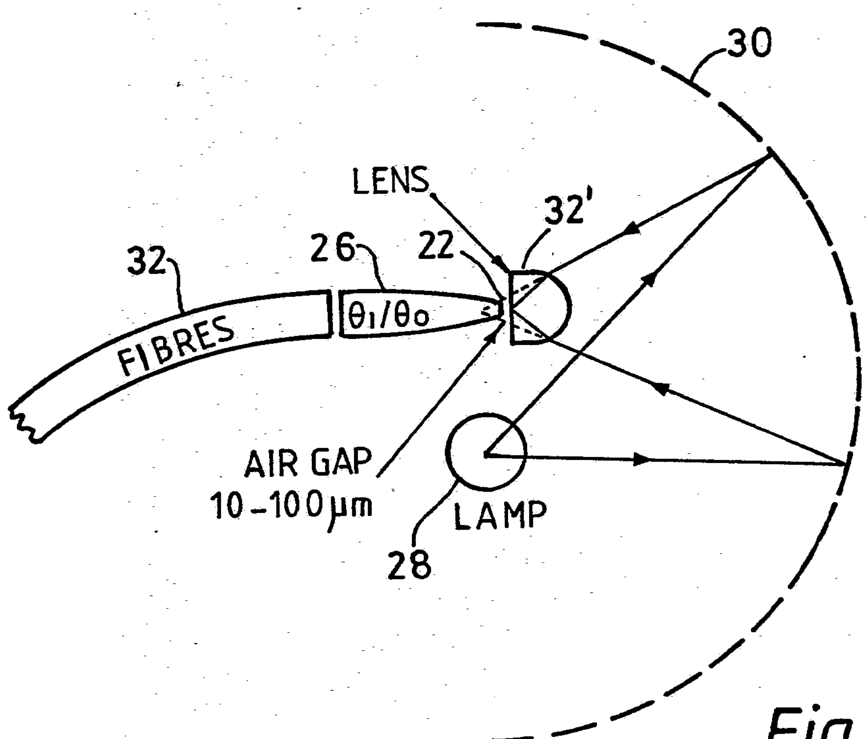


Fig.1



30
26
32
F'
6mm
FIBRE BUNDLE
LAMP
F
28
AXIS
OF
ELLIPSOID
ELLIPSOIDAL
REFLECTOR

Fig.2



30
LENS
32'
32
26
22
FIBRES
θ1/θo
AIR GAP
10-100μm
LAMP
28

Fig.3

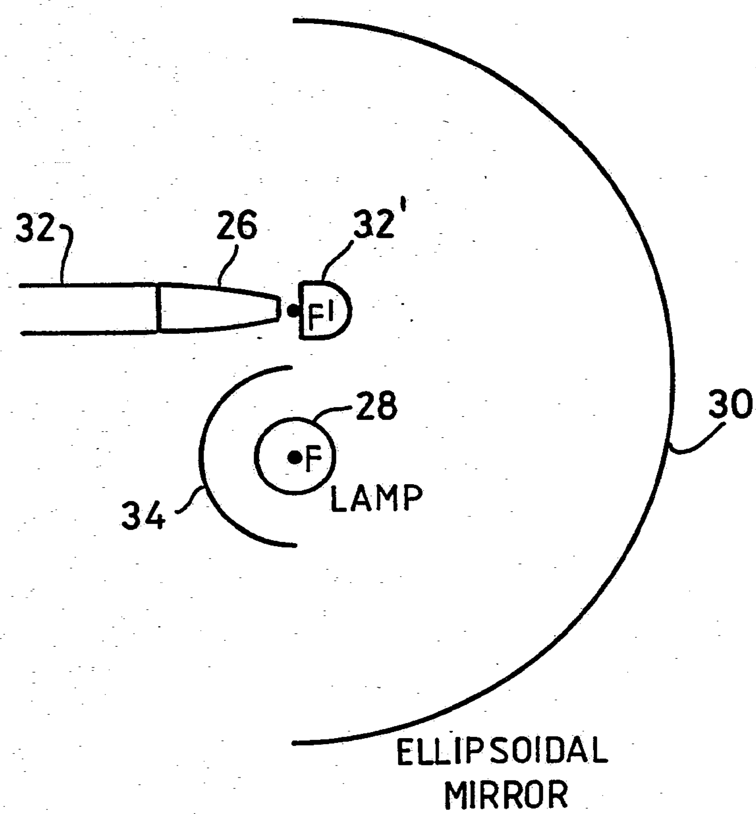


Fig.4

Improvements in and relating to fibre optic coupling

Field of invention

This invention concerns coupling devices for transferring the illumination from one optical fibre to another and for collecting illumination for transmission via optical fibres.

Background to the invention

Current fibre illumination systems tend to suffer from losses due to inefficient coupling of a light source to a fibre bundle and coupling of one end of a fibre bundle to another. A perfectly connected collection system could theoretically achieve the maximum possible efficiency but would not achieve the uniform illumination over the fibre bundle as the image of the filament would be preserved.

It is an object of the present invention to provide a device for collection and emission of light from a fibre bundle or single fibre optic which will improve the collection or emission efficiency and which uses non-imaging optics to produce an even illumination.

Summary of the invention

According to one aspect of the present invention, a device for collecting light for transmission into and along a fibre optic means or for collecting light from the end of

a fibre optic means for transmission therefor, comprises a solid transparent member whose outer surface is formed over a major part of its length by the rotation of part of a parabolic curve about an axis and over the remainder of its length by rotation of a straight line inclined to the axis about the same axis so as to define a truncated conical region tapering from the region defined by the rotation of the section of the parabolic curve, the axis about which the said parabolic section and straight line section are rotated subtending a first angle A relative to the axis of the parabola and the height of the truncated conical section being selected so that the plane of the smaller end of the truncated cone passes through the focal point of the parabola and the included angle B of the cone of which the truncated conical end region forms a part.

The device so formed has a larger diameter end and a smaller diameter end, and when used in conjunction with a fibre optic means the larger diameter end is placed into intimate contact with the ends of the fibre optic means.

The device, which will be referred to as a concentrator, can be moulded in perspex or a similar plastics material or may be formed from glass.

The device conserves light since internal reflections are within the critical angle, ie total internal reflection will be obtained, and the concentrator will thus be lossless apart from the Fresnel losses at entry and exit.

In view of the form of the concentrator the entry angle inside the concentrator is no longer 90°.

If the object is to collect light from a source and cause

the light to enter the concentrator, an optical system is required to put the filament of a lamp effectively in contact with the entry aperture.

According to another aspect of the invention, an auxiliary optical system comprises an ellipsoidal reflector with the filament of a light source located at one focal point and the smaller diameter end face of the concentrator located at the other focal point of the ellipsoidal reflector. The concentrator and filament are thus on the axis of revolution of the ellipse which is rotated to produce the ellipsoidal surface and the design allows all of the light seen by the ellipsoidal reflector to be focussed onto the small diameter end face of the concentrator.

The ellipsoidal surface may be moulded from a suitable material and have a light reflecting surface applied thereto, as by vacuum deposition or the like. In addition, a thermal transmitting coating may also be applied to assist in transmitting away heat collected from the light source.

The disadvantage is that the ellipsoidal reflector has to collect the focus over a numerical aperture (NA) of 1.0 and there are of course geometrical obstructions due to the physical structure of the lamp forming the light source. If the filament is made large enough it may be possible to use a more elaborate arrangement in which an auxiliary lens, similar to a conventional aplanatic front element of a high-power microscope objective, is positioned in front of the smaller diameter end of the concentrator. A small air gap in the range 10 to 100 microns is left between the plane surface of the lens and the small diameter end face of the concentrator, and if n

is the refractive index of the material from which the aplanatic lens is formed, a linear magnification is obtained equal to n^2.

Using an auxiliary lens of this type, the ellipsoidal reflector has only to collect and focus over NA $(1/n^2)$ but the filament would be n times larger than before.

It will be appreciated that only half the output of the lamp is used. It is possible to use a concentric spherical mirror behind the lamp to re-image the filament at unity magnification so as to collect more of the light from the lamp.

If appropriate, the concave spherical mirror may be positioned so that imaging of the filament is made exactly on itself so that the gaps in the filament coils are filled in.

Preferably, a quartz halogen lamp is employed and in that event, the gain achieved by imaging the filament on itself may be very small due to the coiled coil configuration of the usual quartz halogen lamp filament so that the latter appears almost solid when illuminated.

Alternatively, the concave spherical mirror can be orientated so as to image the filament beside itself to form a larger apparent source. This enables a source of lower power to apparently give the same light output.

Alternative lamps are metal halide lamps as supplied by Technical Lamp Supplies Limited which have a colour temperature of 5,500° whilst achieving a small source size.

The invention thus enables light from a relatively low power light source to be collected and introduced almost loss free into the end of a fibre bundle either to achieve a greater amount of light passing through the fibre bundle and available for transmission therefrom or to enable a smaller power lamp to be employed to achieve the same level of illumination.

In a preferred embodiment the value of the angle A is 10.64° and the angle B is 15.76°.

A further parameter of a preferred embodiment of the concentrator is an angle C which is subtended between the axis about which the part parabolic curve is rotated and a line passing through the focus of the original parabolic curve and intersecting the circular locus between the parabolic section and the truncated conical section of the surface of the concentrator, which line also intersects the axis about which the parabolic and straight line sections are rotated to form the concentrator external surface.

In the preferred embodiment of concentrator, this angle C is equal to 42.16°.

The concentrator can work in two ways either as a collector or a transmitter. The description so far is of the concentrator serving as a collector of light and an input device to a fibre bundle.

If located at the opposite end of a fibre optic means, light therefrom would be collected almost loss free and concentrated so as to leave the smaller diameter end of

the truncated conical section at the end of the concentrator.

The light leaving the smaller diameter end of the concentrator can either be directed as a diverging beam for general illumination or can be focussed by means of a lens to form either a less diverging or more diverging beam to achieve a different level and area of illumination.

The invention is of particular application in a portable headlamp in which a battery and lamp are carried in a pocket or on a belt by the user and the lamp is connected to a headband via a fibre optic bundle. The result is a significant reduction in the size and weight of the light transmitting element in the headband and the removal of the need for any lens or other focussing device associated with the headband.

The invention is also of application to the provision of illumination in a so-called loope, in which a small light source is positioned between the two optical systems of a binocular adapted to be worn by a surgeon or other medical specialist for inspection purposes. It will be seen that since the concentrator (now acting as an expander) is no larger than the diameter of the fibre bundle feeding it, the light source to be positioned between the two oculars of the binocular need be only a few millimeters in diameter and yet produce a beam of light for illumination purposes which both is both intense and usefully diverging to provide a pool of light some 10 to 30 centimeters ahead of the binocular.

The nature of the transmission end of the fibre optic

means also lends itself to be packaged in an adjustable device enabling the user to manipulate the light beam to direct light in a number of different directions. This is particularly the case where there is little space between the two oculars of the binocular device and the mounting and packaging of the transmission element itself occupies valuable space therebetween.

It is of course important that light entering a device constructed in accordance with the invention , shall not leave via the surface of the device, and whilst totally internal reflection should cater for all the reflections which can occur within the concentrator, the external surface of the concentrator over the section thereof formed by the rotation of the part parabolic curve, may be coated with a light reflecting medium such as by metalisation.

The invention will now be described by way of example with reference to the accompanying drawings in which:

Figure 1 illustrates a preferred form of light collecting concentrator which can also operate in reverse as an expander,

Figure 2 illustrates one arrangement for collecting light from a light source for entry into a device embodying the invention.

Figure 3 shows an alternative arrangement for collecting light from a light source, and

Figure 4 shows a modification of the arrangement shown in Figure 3.

Detailed description of the drawings

In Figure 1 the concentrator/expander device is formed from a material such as perspex and is preferably moulded. The external shape of the concentrator is formed by generating a part of a parabolic curve extending between the lines 10 and 12 about an axis 14 which itself does not pass through the focal point of the parabolic curve but is displaced from the axis of the parabola and subtends an angle to the parabola axis of 10.64°.

In Figure 1 the axis of the parabola from which the curve extending between 10 and 12 is obtained is denoted by reference numeral 16 and the angle subtended is denoted by A.

The remainder of the external surface of the concentrator between lines 12 and 18 is formed by rotating an inclined straight line section 20, which is tangential to the adjacent end of the parabolic curve, about the same axis 14 so as to form a truncated cone. One half of the included angle of the cone of which section 20 forms a truncated part, is denoted by angle B and in the example given this angle is 15.76°.

Lastly the height of the truncated cone (ie the distance along the axis between lines 12 and 18) is further governed by the fact that the angle C as shown in Figure 1 is 42.16° for the particular example shown.

All light incident on the smaller end surface 22 of the device shown in Figure 1 (irrespective of its angle of incidence thereon) is collected and by total internal

reflection made available at the end face 24 for transmission for example into a fibre optic bundle. If operated in reverse so that light is incident on the larger end surface 24, the device serves to concentrate all such light into and through the end face 22.

The material of the concentrator/expander is preferably PMMA having a refractive index n of 1.490.

A concentrator such as shown takes an input with a solid angle of 360° and outputs it at a numerical aperture (NA) of 0.275 in air.

As shown in Figure 2, an expander 26 (which may be constructed and formed in the manner shown and described with reference to Figure 1) can be used to collect light from a filament source 28 by positioning the latter at the first focus of an ellipsoidal reflector 30 and the end face 22 of the expander 26 at the second focus of the ellipsoidal reflector 30. The end face 24 of the expander 26 is intimately contacted with a fibre optic bundle 32 for conveying light to a remote position.

The collecting capabilities may be improved by incorporating an aplanatic auxiliary lens 32' ahead of the end face 22 as shown in Figure 3. Here an air gap of between 10 and 100 microns is left between the plane face of the lens 32' and the end face 22 of the expander 26.

As shown in Figure 4, the light which would normally be lost to the reflector 30 may be collected by a concave spherical mirror 34 positioned to the rear of the lamp 28 relative to the ellipsoidal reflector 30 and the distance between the reflector 34 and the filament of the lamp 28

adjusted so as to produce any one of a number of possible desired effects such as infilling the filament coil or enlarging the apparent size of the filament.

Although not shown in detail, an arrangement representing a combination of Figures 3 and 4 can be located in a package containing a battery or connectable to an electricity supply for powering the filament and the fibre optic bundle 32 can be conveyed to a position between two oculars of a binocular adapted to be worn by a medical specialist or surgeon and at the remote end of the fibre optic bundle 32 a similar device 26 may be fitted albeit in reverse so as to concentrate the light from the end of the fibre optic bundle into a focussed beam to form a pool of light at a desired distance (typically in the range 10 to 30 cm.) ahead of the binocular.

The invention enables illumination to be applied to such a binocular without the need for lenses and other optical elements at the output end.

Claims

1. A device for collecting light for transmission into and along a fibre optic means or for collecting light from the end of a fibre optic means for transmission therefrom, comprising a solid transparent member whose outer surface is formed over a major part of its length by the rotation of a section of a parabolic curve about an axis and over the remainder of its length by rotation about the same axis of a straight line inclined to the axis so as to define a truncated cone tapering from the region defined by the rotation of the section of the parabolic curve, said axis about which the said parabolic section and straight line section are rotated subtending an angle A relative to the axis of the parabola, and the height of the truncated cone being selected so that the plane of the smaller end of the truncated cone passes through the focal point of the parabola.

2. A device according to claim 1 which said straight line is tangential to the adjacent end of said parabolic curve section.

3. A device according to claim 1 or claim 2 which is moulded in perspex or a similar plastics material or is formed from glass.

4. A device according to any one of claims 1 to 3 and further comprising an auxiliary optical system having an ellipsoidal reflector with the filament of a light source

located at one focal point of the ellipsoidal reflector and with the smaller diameter conical end face of the device being located at the other focal point thereof.

5. A device according to claim 4 in which the ellipsoidal reflector is moulded from a suitable material and having a light reflecting surface applied thereto, as by vacuum deposition or the like.

6. A device according to claim 5 in which a thermal transmitting coating is also applied to assist in transmitting away heat collected from the light source.

7. A device according to any one of claims 4 to 6 in which an auxiliary lens, similar to a conventional aplanatic front element of a high-power microscope objective, is positioned in front of said smaller diameter end.

8. A device according to claim 7 in which a small air gap in the range 10 to 100 microns is left between the plane surface of the auxillary lens and said small diameter end, the linear magnification of the auxillary lens being equal to n^2, where n is the refractive index of the material thereof.

9. A device according to any one of claims 4 to 8 further comprising a concentric concave spherical mirror behind the light source to re-image the filament at unity magnification so as to collect more of the light from the light source.

10. A device according to claim 9 in which the spherical mirror is positioned so that imaging of the filament is

made exactly on itself whereby the gaps in the filament coils are filled in.

11. A device according to claim 10 in which the concave spherical mirror is orientated so as to image the filament beside itself to form a larger apparent source.

12. A device according to claim 10 in which the light source is a quartz halogen lamp, the gain achieved by imaging the filament on itself being very small due to the coiled coil configuration of the usual quartz halogen lamp filament, so that the latter appears almost solid when illuminated.

13. A device according to any one of claims 4 to 11 in which the light source is a metal halide lamp having a colour temperature of about 5,500°.

14. A device according to any preceding claim in which the value of said angle A is 10.64°.

15. A device according to any preceding claim in which one half of the included angle of the truncated cone is 15.76°.

16. A device according to any preceding claim in which a further parameter of the device is an angle C which is subtended between the axis about which the parabolic curve is rotated and a line passing through the focus of said parabola and intersecting the circular locus between the parabolic section and the truncated conical section of the surface of the device, which line also intersects the axis about which the parabolic and straight line sections are rotated.

17. A device according to claim 16 in which said angle is equal to 42.16°.

18. A device according to any preceding claim in which said fibre optic means is packaged in an adjustable device enabling the user to manipulate the light beam to direct light in a number of different directions.

19. A device according to any preceding claim in which, the external surface over the section thereof formed by the rotation of the part parabolic curve is coated with a light reflecting medium, such as by metalisation.

20. A device for collecting light substantially as herein described with reference to, and as shown in, the accompanying drawings.

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